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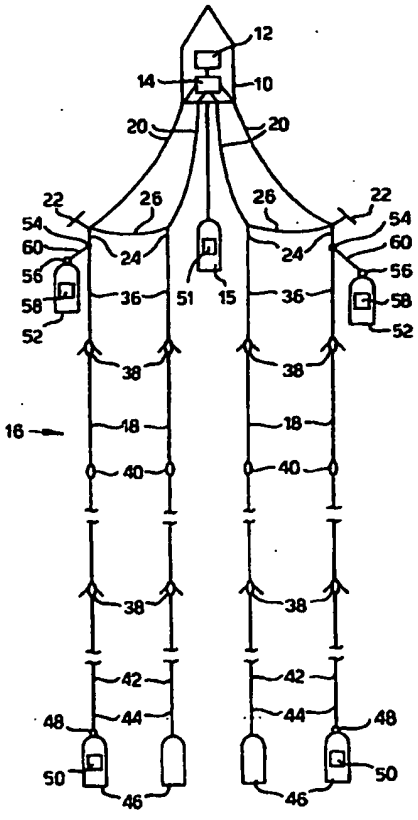

(57) Abstract: In a new method and apparatus for performing a marine seismic survey, an array of parallel seismic streamers (16) containing hydrophones (32) is towed by a survey vessel (10). At least one tailbuoy (46) provided with a GPS receiver (50) is towed by the array, which has a network of acoustic emitters (40) and receivers distributed throughout it for determining the respective positions of the hydrophones with respect to the GPS receiver. To improve the accuracy of the position determinations, at least one further buoy (52) provided with a GPS receiver (58) is connected to be towed by the array from a point somewhere near the forward end of the array, and the positions of at least some of the hydrophones are determined with respect to both GPS receivers.

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MARINE SEISMIC SURVEYING

This invention relates to marine seismic surveying, and is more particularly concerned with methods and apparatus for accurately determining the positions of the sensors in an array of seismic streamers being used to perform a 3D marine seismic survey.

In order to perform a 3D marine seismic survey, an array of marine seismic streamers, each typically several thousand metres long and containing a large number of hydrophones and associated electronic equipment distributed along its length, is towed at about 5 knots behind a seismic survey vessel, which also tows one or more seismic sources, typically air guns. Acoustic signals, or "shots", produced by the seismic sources are directed down through the water into the earth beneath, where they are reflected from the various strata. The reflected signals are received by the hydrophones in the streamers, digitised and then transmitted to the seismic survey vessel, where they are recorded and at least partially processed with the ultimate aim of building up a representation of the earth strata in the area being surveyed.

In order to build up a positionally accurate representation of the earth strata, useful for example for determining the position at which a well should subsequently be drilled into the formations in order to enable hydrocarbons to be recovered, it is essential to determine accurately the respective positions of the seismic sources and the hydrophones for each shot produced by the seismic sources. Currently this is done using respective GPS receivers on the vessel and on one or more tailbuoys towed from the ends of the streamers remote from the vessel, in combination with an acoustic ranging and positioning system based on triangulation and comprising a plurality of relatively high frequency acoustic emitters, or "pingers", and acoustic receivers distributed throughout the streamer array. The GPS receivers are used to determine the respective "absolute"

positions (ie latitude and longitude) of the vessel and the or each tailbuoy, typically to an accuracy of a few metres, while the acoustic ranging and positioning system is used to determine the respective positions of the sources and the hydrophones relative to the absolute positions of the GPS receivers. Acoustic ranging and positioning systems suitable for use in this context are described in our US Patents Nos 4,992,990 and 5,668,775.

Currently, a typical streamer array is 700 metres wide, and comprises eight evenly spaced streamers, each about 4000 metres long. The streamers are towed by their lead-ins, ie the armoured electrical cables that convey electrical power, control and data signals between the vessel and the streamers, as described in our US Patent No. 4,798,156, and their spread is controlled and maintained by MONOWING deflectors of the kind described in our US Patent No. 5,357,892. However, in order to increase the efficiency and reduce the cost of marine seismic surveys, it is desirable to use even wider arrays containing even more streamers, for example by using the technique described in our PCT Patent Application No. PCT/IB98/01435 (WO 99/15913). But as the streamer arrays get wider and longer, the cumulative errors in the relative position measurements made by the acoustic ranging and positioning system tend to increase with increasing distance from the absolute positions determined by the GPS receivers, especially for the outer streamers of the arrays.

It is an object of the present invention to alleviate this problem.

According to a first aspect of the present invention, there is provided a seismic streamer array for use in marine seismic surveying, the array comprising:

a plurality of substantially parallel seismic streamers each having a forward end adapted to be connected to a towing vessel, a rearward end and a multiplicity of seismic sensors distributed therealong:

at least one tailbuoy which is connected to the rearward end of one of the streamers and which is provided with a GPS receiver;

and a plurality of acoustic emitters and receivers distributed throughout the array for determining the respective positions of parts of the array with respect to at least the GPS receiver;

wherein there is provided at least one further buoy which is connected to one of the streamers so as to be towed thereby at a position substantially forward of the tailbuoy and which is provided with a further GPS receiver and an acoustic emitter and/or receiver for use in co-operation with said plurality of acoustic emitters and receivers in determining the respective positions of parts of the array with respect to the further GPS receiver.

In a preferred implementation of this first aspect of the invention, the forward end of each streamer includes a stretch portion, and the further buoy is connected to the stretch portion.

Advantageously, the array includes two such further buoys, each connected to a respective one of the two outer streamers of the array.

Preferably, the or each further buoy is connected to its streamer at a connector by means of which signals are transmitted in both directions between the further buoy and its acoustic emitter and/or receiver on the one hand and the streamer on the other hand.

The or each further buoy is preferably connected to its streamer by means of a stretch portion, which is preferably at least twenty five metres long and which is preferably provided with a fairing.

Conveniently, the plurality of acoustic receivers is constituted by some or all of the seismic sensors.

According to a second aspect of the invention, there is provided a method of performing a marine seismic survey, the method comprising the steps of:

(a) towing a seismic streamer array over an area to be surveyed with a towing vessel, the array comprising: a plurality of substantially parallel seismic streamers each having a forward end adapted to be connected to the towing vessel, a rearward end, and a multiplicity of seismic sensors distributed therealong; at least one tailbuoy which is connected to the rearward end of one of the streamers and which is provided with a GPS receiver; and a plurality of acoustic emitters and receivers distributed throughout the array;

(b) directing acoustic signals downwardly into said area for reflection from earth strata therein;

(c) detecting the acoustic signals reflected from the earth strata with the seismic sensors; and

(d) determining the respective positions of at least some of the seismic sensors with respect to at least the GPS receiver using at least some of said acoustic emitters and receivers;

(e) further comprising towing at least one further buoy at a position substantially forward of the tailbuoy by attaching it to one of the streamers, said further buoy being provided with a further GPS receiver and an acoustic emitter and/or receiver; and

(f) determining the respective positions of at least some of the seismic sensors with respect to the further GPS receiver using some of said acoustic emitters and receivers.

In a preferred implementation of this second aspect of the invention, the further buoy is attached to the forward end of its streamer.

Preferably two such further buoys are provided, each attached to a respective one of the two outer streamers of the array, and position determining step (f) is effected with respect to the respective GPS receivers of both further buoys.

Conveniently, some or all of the seismic sensors are used as said plurality of acoustic receivers.

The invention will now be described, by way of example only, with reference to the accompanying drawings, of which:

Figure 1 is a somewhat diagrammatic plan view of a seismic survey vessel performing a marine seismic survey using a method and a seismic streamer array in accordance with the present invention;

Figure 2 is a schematic partly cut away view of a portion of one of the streamers of the streamer array of Figure 1; and

Figure 3 is a side view of part of the seismic streamer array of Figure 1.

The seismic survey vessel shown in Figure 1 is indicated generally at 10, and is preferably as described in our PCT Patent Application No. PCT/GB98/01832 (WO 99/00295). The vessel 10 is provided with a GPS receiver 12 coupled to a data processor 14, and is shown towing a seismic source 15, typically a TRISOR multiple air gun source of the kind described in our US Patent No 4,757,482, and an array 16 of four substantially identical streamers 18. However, it will be appreciated that, in practice, many more than four streamers can be towed, for example by using the techniques described in our PCT Patent Application No PCT/IB98/01435 (WO 99/15913). The streamers 18 are towed by means of their respective lead-ins 20 (ie the high strength steel- or fibre-reinforced electrical or electro-optical cables which convey electrical power, control and data signals between the vessel 10 and the streamers), and their spread is controlled by two of the aforementioned MONOWING deflectors, indicated at 22, connected to the respective forward ends 24 of the two outermost streamers. The deflectors 22 act in co-operation with respective spreader lines 26 connected between the forward end 24 of each outer streamer 18 and the forward end 24 of its adjacent streamer to maintain a substantially uniform spacing between the streamers.

Each streamer 18 can be as described in our PCT Patent Application No PCT/GB99/01544 (WO 99/60421), and is made up of a large number of substantially identical streamer sections 18a connected together end to end. Each streamer section 18a comprises a tubular outer plastics skin 28 which contains several elongate stress members 30, eg of Kevlar, and a multiplicity of substantially uniformly spaced apart hydrophones 32 separated by kerosene-saturated plastics foam spacer material 34, as best seen in Figure 2.

The forward end 24 of each streamer 18 comprises at least two stretch sections 36, each at least 50 metres long, which serve as vibration dampers to reduce the effect on the streamer of vibrations produced by the towing system connected to the forward end of the streamer.

Each streamer 18 has a plurality of "birds" 38, preferably of the kind described in our PCT Patent Application No PCT/GB97/03507 (WO 98/28636), distributed at 200 metre intervals therealong, for controlling the streamer's depth and steering it laterally. Additionally, each streamer 18 has emitters (or "pingers") 40, typically of the type available from Sonardyne International Ltd of the UK, uniformly distributed therealong, the pingers being interleaved between the birds 38.

The rearward ends 42 of the streamers 28, ie the ends remote from the vessel 10, are connected via respective stretch sections 44 similar to the stretch sections 36 to respective tailbuoys 46, the two outermost tailbuoys being provided with respective pingers 48 similar to the pingers 40 and respective GPS receivers 50.

The seismic source 15 is also provided with a GPS receiver, indicated at 51.

In accordance with the present invention, the array 16 is provided in the region of its forward end 24 with two further buoys or floats 52. More specifically,

the further floats 52 are respectively connected to the two outermost streamers 18 at respective watertight electro-optical "tee" connectors 54 positioned between the two stretch sections 36 at the forward ends 24 of the outermost streamers, so as to be towed by the streamers. The buoys 52 can be substantially identical to the tailbuoys 46, are provided with respective pingers 56 and GPS receivers 58, and are connected to their respective connectors 54 by respective stretch sections 60. Although the buoys 52 are shown in Figure 1 as offset with respect to their streamers for clarity, in practice they are substantially in line with the streamers.

One of the buoys 52, and its connection to its streamer 18, are shown in more detail in Figure 3, where it can be seen that the "tee" connector 54 has a main body 62 connected in series between the stretch sections 36 of the streamer by way of a male coupler 64 at its forward end and a female coupler 66 at its rearward end. The body 62 has an out-take 68 terminating in another female coupler 70, which is connected via an adapter section 72 and a power section 74 to the stretch section 60. The body 62, the out-take 70 and the couplers 64, 66, 70 have a common, or unitary, outer housing made from titanium.

The stretch section 60 is typically 50 to 75 metres long, in dependence upon the chosen streamer operating depth, and is provided over at least the rearmost 25 metres of its length with a fairing of the kind described in our PCT Patent Application No PCT/IB98/01945 (WO 99/34237). Both of these features reduce the transmission of vibration produced by the buoy 54 and the stretch section 60 to the streamer 18.

The pinger 56 associated with the buoy 54 is actually secured to the stretch section 60 at a point just forward of the buoy.

In use, the seismic source 15 and the seismic streamer array 16 are deployed from the vessel 10 and towed at about 5 knots in the configuration

shown in Figure 1. The source 15 is periodically fired, and the resulting reflected seismic data signals are detected by the hydrophones 32 in the streamers 18 and transmitted to the data processor 14 in the vessel 10 via the lead-ins 20, as described earlier. Concurrently, and for each shot produced by the source 15, the position of the source is determined using the GPS receiver 51 provided on the source, while the respective positions of the hydrophones 32 are determined using the pingers 40, 48, 56, selected ones of the hydrophones 32 as receivers for the acoustic ranging signals produced by the pingers, and the techniques described in the aforementioned US Patents Nos 4,992,990 and 5,668,775. However, the positions of the hydrophones 32 in at least the forward part of the array 16 are referenced to absolute positions determined by the GPS receivers 58 in the buoys 52. Indeed, the positions of many of the hydrophones 32 are determined with respect to more than one of the GPS receivers 50 and 58, and then calculated using the least squares method or averaged using weighted averaging. As a result, the positions of the hydrophones 32 are determined with greater accuracy than was possible hitherto.

Many modifications can be made to the described embodiment of the invention.

For example, the stretch section 60 can be reduced in length in dependence upon its chosen operating depth, but typically not to less than about 25 metres.

Also, the buoys 52 can be connected further back in the array 16 than the front, eg near the middle of the array, with their connectors 54 being connected between two active streamer sections, or further buoys with GPS receivers and acoustic pingers can be provided near the middle of the array in addition to the buoys 52 at the front of the array. But in the limit, the use of just one of the buoys 52 well forward of the tailbuoys 46 provides significant benefits.

CLAIMS

1. A seismic streamer array for use in marine seismic surveying, the array comprising:

a plurality of substantially parallel seismic streamers each having a forward end adapted to be connected to a towing vessel, a rearward end and a multiplicity of seismic sensors distributed therealong:

at least one tailbuoy which is connected to the rearward end of one of the streamers and which is provided with a GPS receiver;

and a plurality of acoustic emitters and receivers distributed throughout the array for determining the respective positions of parts of the array with respect to at least the GPS receiver;

wherein there is provided at least one further towed buoy which is connected to one of the streamers so as to be towed thereby at a position substantially forward of the tailbuoy and which is provided with a further GPS receiver and an acoustic emitter and/or receiver for use in co-operation with said plurality of acoustic transmitters and receivers in determining the respective positions of parts of the array with respect to the further GPS receiver.

2. An array as claimed in claim 1, wherein the forward end of each streamer includes a stretch portion, and the further buoy is connected to the stretch portion.

3. An array as claimed in claim 1 or claim 2, wherein the array includes two such further buoys, each connected to a respective one of the two outer streamers of the array.

4. An array as claimed in any preceding claim, wherein the or each further buoy is connected to its streamer at a connector by means of which signals are transmitted in both directions between the further buoy and its acoustic emitter and/or receiver on the one hand and the streamer on the other hand.

5. An array as claimed in any preceding claim, wherein the or each further buoy is connected to its streamer by means of a stretch portion.

6. An array as claimed in claim 5, wherein the stretch portion is at least twenty five metres long.

7. An array as claimed in claim 5 or claim 6, wherein the stretch portion is provided with a fairing.

8. An array as claimed in any preceding claim, wherein the plurality of acoustic receivers is constituted by some or all of the seismic sensors.

9. A method of performing a marine seismic survey, the method comprising the steps of:

(a) towing a seismic streamer array over an area to be surveyed with a towing vessel, the array comprising: a plurality of substantially parallel seismic streamers each having a forward end adapted to be connected to the towing vessel, a rearward end, and a multiplicity of seismic sensors distributed therealong; at least one tailbuoy which is connected to the rearward end of one of the streamers and which is provided with a GPS receiver; and a plurality of acoustic emitters and receivers distributed throughout the array;

(b) directing acoustic signals downwardly into said area for reflection from earth strata therein;

(c) detecting the acoustic signals reflected from the earth strata with the seismic sensors; and

(d) determining the respective positions of at least some of the seismic sensors with respect to at least the GPS receiver using at least some of said acoustic emitters and receivers;

(e) further comprising towing at least one further buoy at a position substantially forward of the tailbuoy by attaching it to one of the streamers, said further buoy being provided with a further GPS receiver and an acoustic emitter and/or receiver; and

(f) determining the respective positions of at least some of the seismic sensors with respect to the further GPS receiver using some of said acoustic emitters and receivers.

10. A method as claimed in claim 9, wherein the further buoy is attached to the forward end of its streamer.

11. A method as claimed in claim 9 or claim 10, wherein two such further buoys are provided, each attached to a respective one of the two outer streamers of the array, and position determining step (f) is effected with respect to the respective GPS receivers of both further buoys.

12. A method as claimed in any one of claims 9 to 11, wherein some or all of the seismic sensors are used as said plurality of acoustic receivers.

Fig.1.

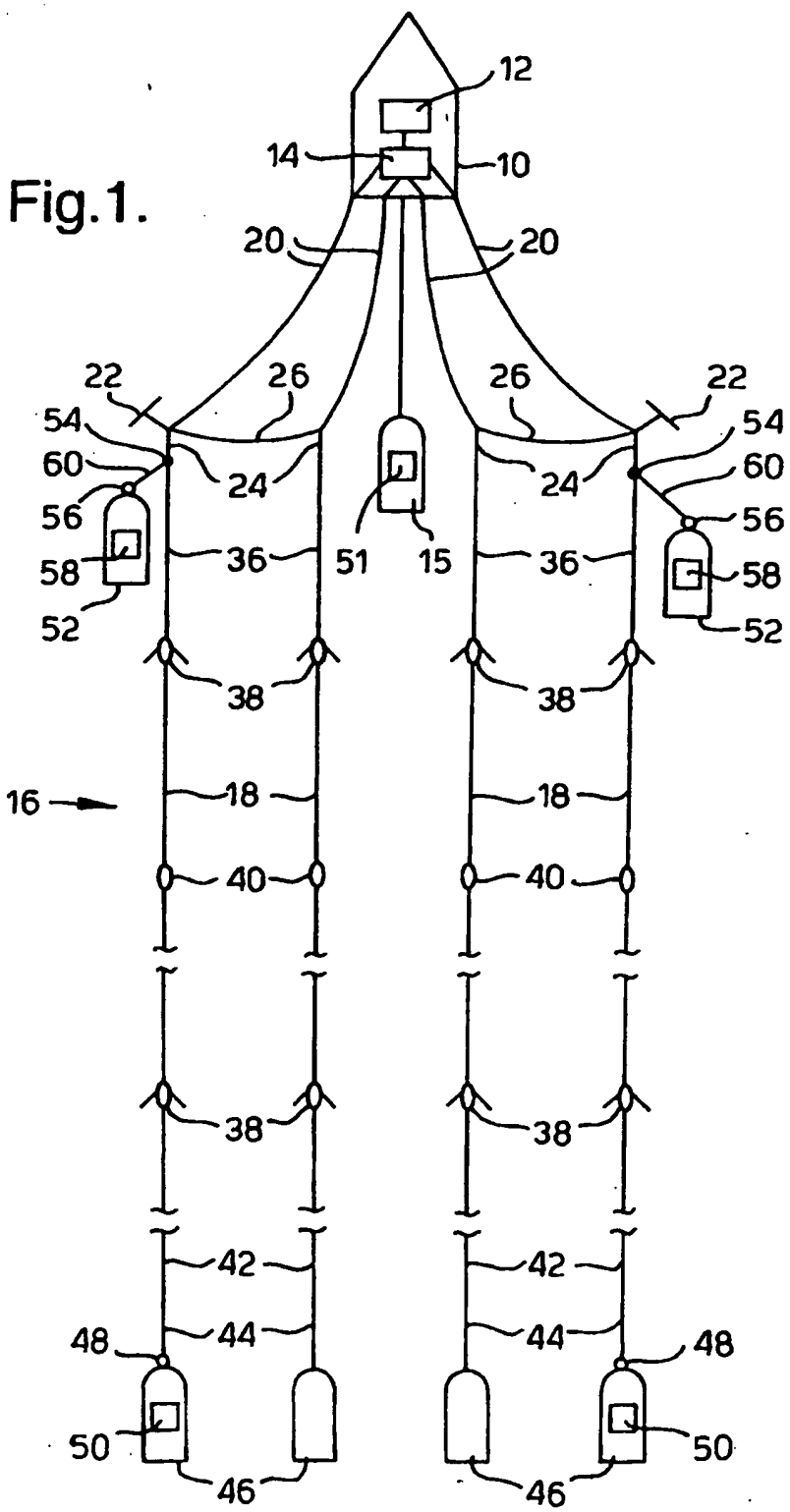
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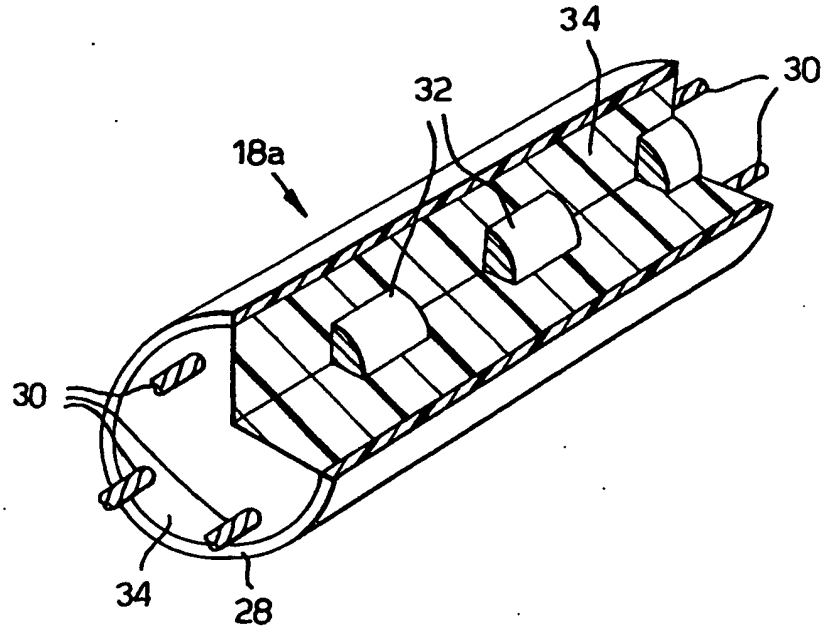
Fig.2.



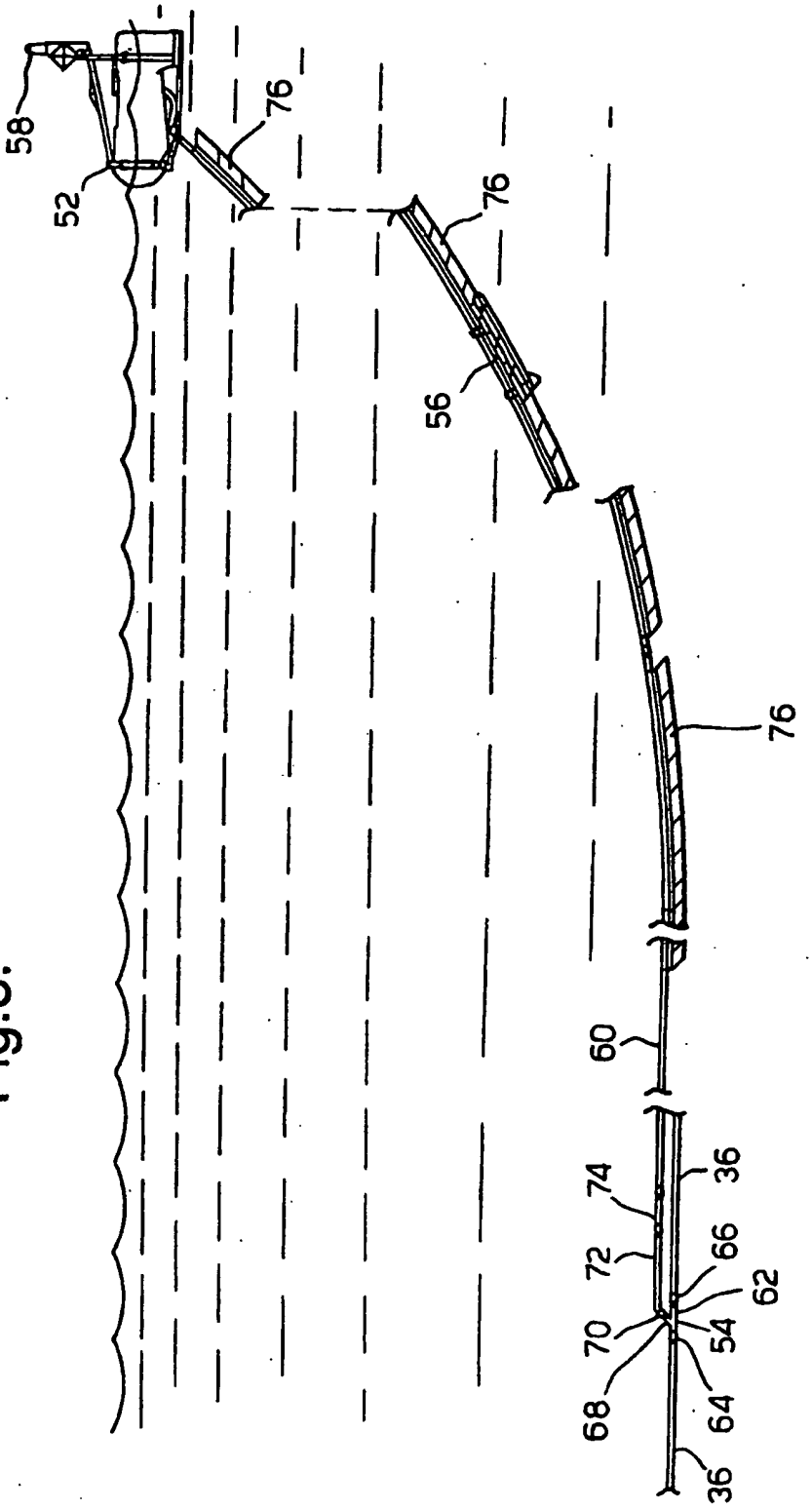


Fig.3.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/00210

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01V1/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 668 775 A (HATTELAND KJELL) 16 September 1997 (1997-09-16) cited in the application column 3, line 21 - line 65 column 5, line 23 - line 35	1,3,7-9
Y	EP 0 518 146 A (TRIMBLE NAVIGATION LTD) 16 December 1992 (1992-12-16) page 4, line 52 - line 58	1,3,7-9
A	US 6 009 042 A (CHAMBERS RONALD E ET AL) 28 December 1999 (1999-12-28) column 4, line 33 - line 41	1,9
A	US 5 616 059 A (SOLOMON FRANK) 1 April 1997 (1997-04-01) column 2, line 34 - line 54	1,9

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 May 2001	23/05/2001

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

.ormation on patent family members

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